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ScienceDirect
Energy Procedia 39 (2013) 454 – 460
Energy Procedia

Asian Nuclear Prospects 2012
(ANUP2012)

The α contamination monitor based on LARD

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Abstract

The LRAD-based monitor was designed to detect the residual contamination of the equipment that needs to be efficiently monitored .The monitor measures the current created by the ions which are generated by the interact ion of alpha particles with air and which can be transported over significant distances (several meters) in an airflow generated by a small fan. The STM32F10x microcontroller was employed in building the hardware platform to achieve high-precision micro-current measurements. The detector can measure the small electric current of ions up to the level of *fA* and the sensitivity of this detector is about 5.29307*fA/Bq*. Some problems are discussed and put forward in the paper such as how to measure the radiation activity by experimental calibration, and how to improve the measurement accuracy of micro-current, and so on.

Selection and peer-review under responsibility of Institute of Nuclear and New Energy Technology, Tsinghua University

Keywors: LARD; alpha particles;STM32F;radioaction activity

1. Introduction

In the decommissioning of nuclear facilities safety requirements, emphasizing the importance of monitoring facilities, systems, equipment, venues, retired to the completion of the state retained the residual radioactive surface contamination levels, to keep abreast of and decommissioning activities related to the actual level of protection and safety[1]. Long-distance α measurement (Long range alpha

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Selection and peer-review under responsibility of Institute of Nuclear and New Energy Technology, Tsinghua University
doi:10.1016/j.egypro.2013.07.236

detector, LRAD) is an important classification means of large or irregular shape of the nuclear facilities. LRAD technology-based detector (referred to as the LRAD detector), uses the method of collection of α-particles in the air generated by ionization ion indirect detection of alpha particles, accoriding to the size of the ionization current measured to estimate the activity of α radiator[2]. Such detectors have the following advantages:

- They can monitor uneven or irregular surfaces (all kinds of tools or appliances, etc.);
- They can monitor what the traditional detector can not do within the cavity surface (tube-shaped and tubular objects the inner surface);
- They can monitor a larger area of the α pollutants (overalls, human body, etc.) [3-5].

The sensitivity and application of traditional alpha monitors is limited by the short range of alpha particles in air (typically 10 cm)[6].Detecting small amounts of alpha-emitting contamination inside pipes presents particular problems. Monitors based on long-range alpha detection (LRAD) detect ionization of the ambient air rather than the alpha particles themselves[7,8]. A small fan draws the ions into an externally mounted ion detector. Thus, the air in the pipe serves as both the detector gas and the mechanism for transporting the alpha-induced ions to a detection grid outside of the pipe. All of the ions created by all of the contamination in the pipe can be measured in a single detector[9]. To summarize, LRAD-based monitors are not limited by the range of the alpha particle, but rather by the lifetime of the ions (the observed several second lifetime allows transport of the ions over many meters or tens of meters). The LRAD-based monitors can provide real-time, in-situ measurements to aid in operational decisions about pipe removal and disposition [10,11].

In early 1990s, the detection sensitivity of a LRAD detector designed by Mac Arthur DW is $(3.78 \pm 0.18) \times 10^{-15} A/Bq$[12]. In 2008, the Chinese Academy of Engineering Physics Experimental can reach $6.53 \times 10^{-15} A/Bq$ [13]. Above the detectors are generally connected with the weak current measuring device (such as Keithley electrometer). But the weak current measuring device lack of direction in measuring the detector current signal, such as we couldn't set flexible in the average processing times of time and data[14].

In this paper, for the purpose of measuring α-radiation of irregular pipeline, we designed a monitor based on LRAD. The monitor consists of five main compositions: the ionization chamber, *fA* level micro-current measuring device, microprocessor control system, the computer communication interface, and battery power, see Fig 1. The detector changes the ion pairs to a dc current, and the current is proportional to the number of ions created by the alpha particle. and, hence, the amount of radiation activity present. The background value can be automatic measured and removed from the measurement results. At the same time, designing the PC communication interface can facilitate the radioactive sources positioning and measurement methods.

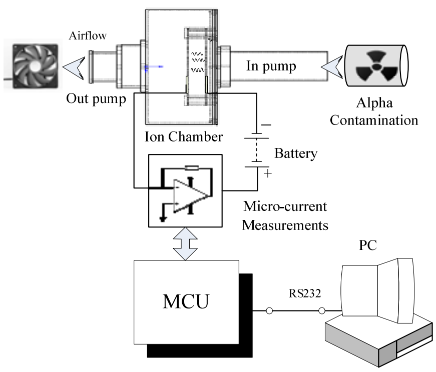

Fig.1 System design diagram

2. LRAD Ion Detector Design

Being different with the pulse detector, the ionization chamber detector's structure is relatively simple. The output signal of the current ionization detector is the cumulative effect of many particles, and output signal strength is proportional to the radiation particle fluence and energy in the radiation field [15].

In air, an alpha particle loses about 35 eV per ion pair produced. Thus, a 5-MeV alpha particle will produce about 150,000 ion pairs as it loses energy in air . These charges can be transported by an air current into an ion detector located up to several meters away from the initial decay. The LRAD detector transports these ion pairs to a signal grid, where a dc current is produced and read by an electrometer. The current is proportional to the number of ions created by the alpha particle, and, hence, the amount of activity present. The saturation current and pollution activity has the following relationship:

$$I_o = \frac{E \times e \times A}{E_0 \times 2} \tag{1}$$

Where: I_O is produced by the ionization chamber saturation current; E is the energy of charged particles; E_0 is the average ionization successful; A is the activity.

The detector will measure the actual radiation activity to determine the linear relationship between the actual radiation activity and measuring current I_B:

$$A = K_1 \times I_S + K_2 \tag{2}$$

Determine where K_1 and K_2 calibration value, to achieve the calibration of radiation activity by current measurement.

This detector consist of two perforated copper plates mounted on Lexan stand-offs. The first plate is used as our collect plate; the second is a voltage plate , see Fig 2. The 200V applied to the voltage plate provide enough potential to ensure efficient ion collection on the collect plate. The current that is produced is displayed on our data acquisition system.

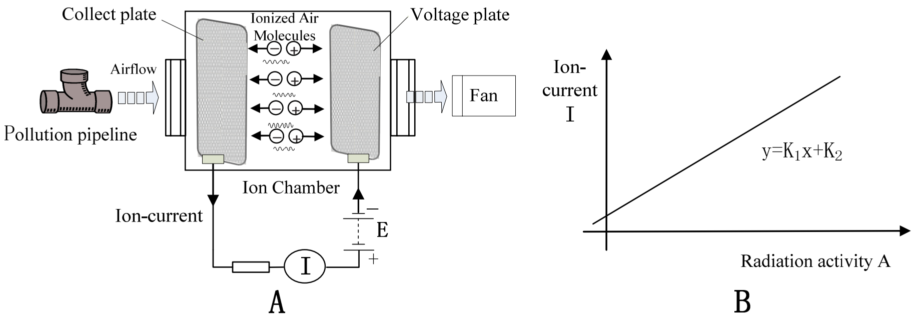

Fig.2 Schematic diagram of the parallel-plate gas ionization chamber

A single fan mounted on the input side of the electrostatic precipitator blows air through the pipe or duct. The ions are collected and passed to the detector, where the current is processed in the same manner as previously described. The fan(model PMD2408PMB1-A (DC24V ≈ 9.6W)) which voltage 0-24V adjustable blow the air flow with the fan voltage changes linearly.

3. Electronics signal processing

Under the normal condition, the weak current of the ionization chamber detector output signal is converted to voltage signal, and digital access to the radiation particle energy deposition information. Signal processing systems use the ARM Cortex-M3 embedded microprocessor STM32F100X as the core[16]. The design idea is to extend the peripheral chips with STM32F100X interface, peripheral chips expansion of functional modules: I-V signal acquisition and conversion, display part, and data communication interface module composition, see Fig 3. These modules which uses a standardized modular design method, are independent between function and circuit structure. Different specific requirements can be easily configured for the basic structure of the intelligent controller.

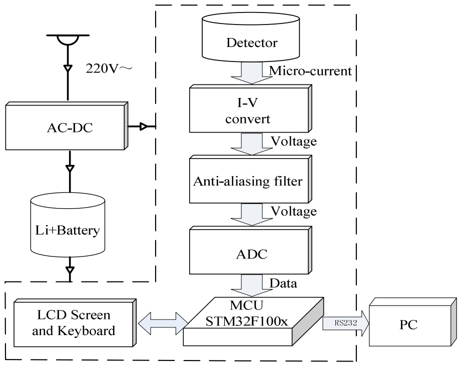

Fig.3 Electronic signal processing system

The micro-current (less than $10^{-6}A$) measurement circuit performance determine the sensitivity and resolution of the instrument. There are two ways in typical weak current measurements: capacitance integral and cross-resistance measurement method. The design is selected in cross-resistance measurement, to produce a voltage drop to complete the I-V conversion, according the jumper resistor. In order to achieve high precision and stability of the rapid measurement and continuous changes in the weak current, see Fig 4.

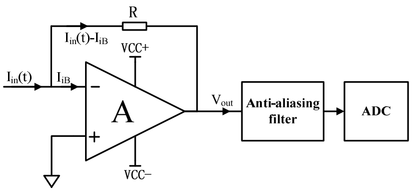

Fig.4 Fundamental diagram of transimpedance method

$I_{in}(t)$ is the measured weak current, I_{iB} is the op amp input bias current, R is connected across resistor, A is the op amp. I-V conversion of the output voltage and measured current relationship, such as formula (3) shown:

$$V_{out} = -\left[I_{in} - I_{iB}\right] \times R \tag{3}$$

In the formula: V_{out} is the output voltage; when $I_{iB} << I_{in}$ (t), I_{iB} can be ignored.

Transimpedance amplifier, select the electrometer op amps AD549 which has a very low input bias current monolithic and input bias current $I_{iB} < 60fA$.

Anti-aliasing filter processing circuit to filter out the inherent noise and external noise interference.

ADC choose to use TI's high-performance low-noise high-resolution analog to digital technology chip ADS1255 which based on the Δ-Σ converter.

These methods measures can contribute to ensure the accuracy of the measurement 23*Bit* and resolution of the weak current measurement techniques to *fA* ($1\ fA = 10^{-15} A$) level.

4. Result and the system performance test

4.1. Micro-current measurement test

Using Keithley 6514 programmable electrometer (resolution better than 1*fA*) compared experimental tests, as shown in Figure 5. Ambient temperature is 15 ℃, the measurement time 120s, the measurement data relative error within ± 0.4%.

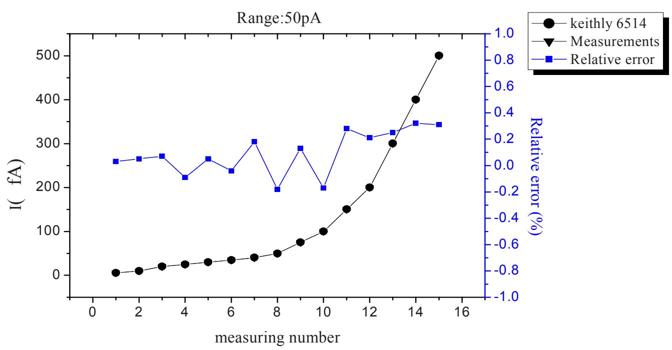

Fig.5 Actual measurement data

4.2. System Stability Test

After 30 minutes warm-up, the instrument under the conditions of the intrinsic background measurement, the measurement time is 2min, intrinsic background measuring average 0.13*mv*.

24.05 *Bq* of ^{239}Pu standard source placed in the detector nozzle, measurement time 120*s*, the fan voltage of 12V, measuring frequency of 342 times. The stability test result is presented as histograms, see Fig 6. Calculated by the mean and relative standard deviation formula: the mean of 342 readings 1.28, standard deviation 0.026 and coefficient of variation (C.V = 100% ×standard deviation / mean) 2.059%.

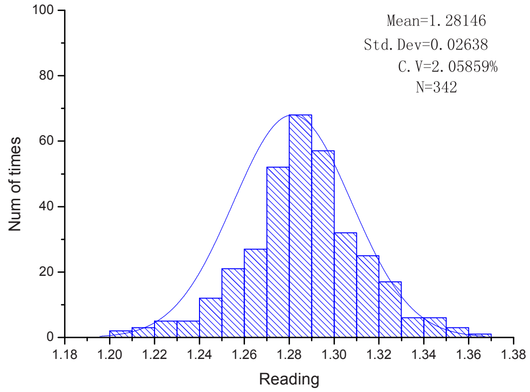

Fig.6 System stability test results

It can be seen from the statistical analysis of the test, the instrument has good stability, in line with the requirements of statistical fluctuation.

4.3. Instrument detection sensitivity test

Five ^{239}Pu α sources in larger range of activity gap (activity: 2.38*Bq*, 24.00*Bq*, 111.33*Bq*, 181.67*Bq*, 5.00×10^3*Bq*) were measured, ionization current corresponding with the radioactive source, to detect the sensitivity of the measurement system, measuring the different intensity of radiation source to the detector response. The data obtained is presented as a line graph, see Fig 7. The line graph gives the 239Pu α source activity, its x and y positions for the graphs, the current reading (*fA*), and the corresponding activity (*Bq*) of radioactive source. The conversion from *fA* to *Bq* is 5.29307×*fA*+1951.28, while the 5.29307 is sensitivity of the detector. The linear correlation coefficient square R^2 is greater than 0.9996, so the radioactive source shows a good linear relationship between the response of the measuring system.

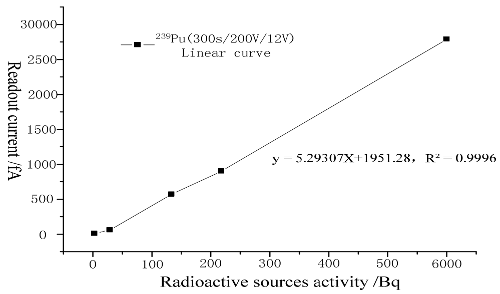

Fig.7 The relationship curves of current and radiation activity

5. Conclusion

When decommissioning of nuclear facilities, processing the low-level radioactive alpha contamination measurement of pipes is a more difficult task. This design of the α radiological survey instrument to a more accurate measurement of the average pollution levels within the pipe after decontamination, has great significance for judgment metal pipe after decontamination achieve the clearance levels. The equipment has been designed debug and experimental measurements, the detection sensitivity of 5.29307*fA/Bq*, to meet actual needs. However, radiation is measured for different pipe diameter measurement, the radiation source positioning problem needs further study, so as to make the instrument plays a greater role in other radiation monitoring in the decommissioning of nuclear facilities.

Acknowledgements

TUO Xian-guo is grateful to the China National Science Foundation for his Distinguished Young Scholars （Grant No.41025015）.This research is supported by the Sichuan Provincial Science and technology support program（ Grant No.2011SZ0182）and by the Science and Technology Project of Chengdu（ Grant No.10GGYB 323GX-023）.

References

[1]REN Xianwen, Environmental Safety in Decommissioning of Nuclear Facilities[J].Radiaction Protection Bulletin, 2006,26(1),p.1-5.

[2]LIU Jianzhong, JIN Gen, MA Liping, HAN Jingquan. A study of measuring α particle by the principle of ion col lection[J]. Chinese Journal of Nuclear Science and Engineering, 2007,27(1),p.77-85.

[3] D.W. MacArthur, K. S. Allander ,J. A. Bounds, and K.B. Butterfield, "Small Long-Range Alpha Detector (LRAD) with Computer Readout," Los Alamos National Laboratory publication LA-12199-MS, October 1991.

[4] Monitoring Airborne Alpha-Emitter Contamination," Los Alamos National Laboratory report LA-UR-97 -4609(March,1998).

[5] J.E.Koster, J.A. Bounds, P.L. Ken, P.A. Steadman, C.R.Whitley. "Whole Body Personnel Monitoring via Ionization Detection," Los Alamos National Laboratory report LA-UR-97-4608(March,1998).

[6]WU Xuemei, TUO Xianguo, LI Zhe, LIU Mingzhe, etal. Application of BP neural network for LRAD-based alpha contamination monitoring inside pipes [J].NUCLEAR TECHNIQUES, 2012, 35(5),p.369-374.

[7]F.H. Attix. Introduction to Radiological Physics and Radiation Dosimetry[M].Wiley-VCH verlag GmbH & Co.KGaA,Weinheim,2004.

[8] D.W. MacArthur. "LRAD Surface Monitors," Los Alamos National Laboratory report LA-12524-MS (1993).

[9] J. E. Koster, J. Bounds, J.G. Conaway, D.W. MacArthur, M. Rawool-Sullivan, P.A. Steadman, etal. "Monitoring for Alpha Emitters in High-Airflow Environments," LA-UR-96-1428 (May, 1996).

[10]J. D. Johnson, A. W. Bond, J. A. Bounds, S. W. Hanson, D. W. MacArthur, W. D. Moss. "A Real-Time Alpha Monitoring System for Radioactive Liquid Waste," Los Alamos National Laboratory report LA-UR-95-410(March, 1995).

[11] C.R.Whitley, J.A. Bounds, P.A. Steadman.A Portable Swipe Monitor for Alpha Contaniination[J] IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL.45, NO. 3, JUNE 1998,p.533-535

[12] D.W. MacArthur, K.S. Allander, Bounds JA, etal. Long-range Alpha Detector[J]. Health Phys,1992,63:324.

[13] TAN Zhaoyi,CHANG Ruimin, LI Ye. Research on Pipeline Surface Contamination Level Monitoring Using Ionization Chamber[J].JOURNAL OF ELECTRONIC MEASUREMENT AND INSTRUMENT, 2008,22(6),p.108-111.

[14] D.W. MacArthur, P. L. Aamodt, J. A. Bounds, J.E. Koster. "Tritium Monitoring of Groundwater and Surfaces," Los Alamos National Laboratory report LA-UR-99-17 (March, 1999) .

[15] P. L. Kerr, J. E. Koster, Kevin Macy,Jay Cook."Real-Time Alphas Emitter Assay of Large Volumes," Los Alamos National Laboratory report LA-UR-96-3983 (March, 1999)

[16] RM0008 Reference Manual-STM32F101xx, STM32F102xx, STM32F103 xx,STM3 2F105xx and STM32F10 7xx advanced ARM-based 32-bitMCUs[EB/OL].[2009-6]http://www.st.com.